Effects of new neutrino-neutrino interactions in dense neutrino gases

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(Based on MB, Mirizzi, Serpico, Phys. Rev. D78, 113004 (2008) [arXiv:0810.2297])

1 Dense neutrino gases

1. Dense neutrino gases

2. Nonstandard interactions and their implications

3. Summary and conclusions

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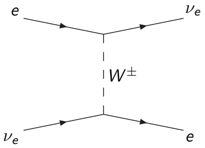

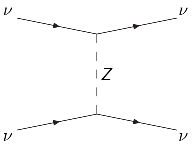

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- The effect of neutrino-neutrino interactions is non-linear

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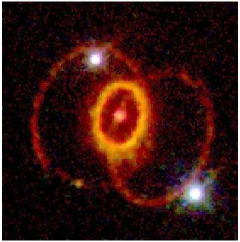

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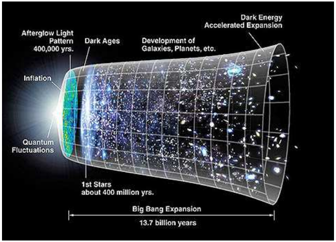

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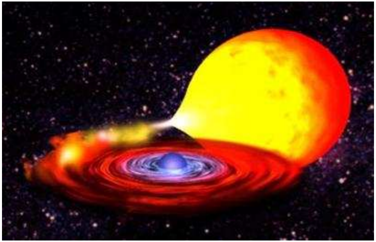
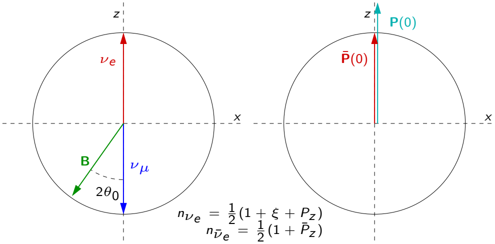
  - Coalescing neutron stars



Polarization vector treatment



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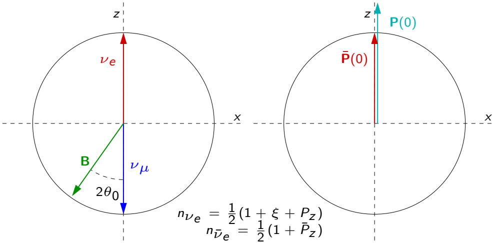

$$n_{\nu_e} = \frac{1}{2}(1+\xi+P_z)$$
$$n_{\bar\nu_e} = \frac{1}{2}(1+\bar P_z)$$

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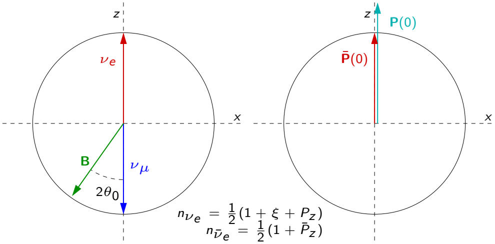

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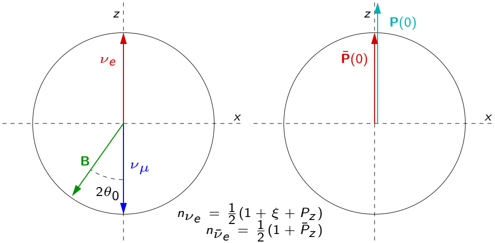

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- The polarization vectors rotates around a vector determined by the Hamiltonian of the system

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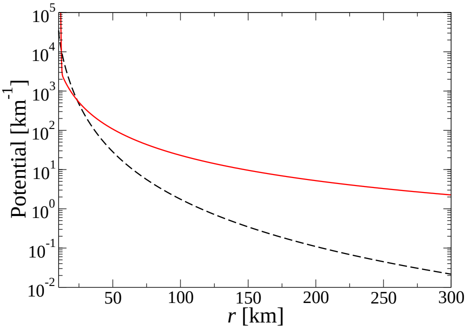
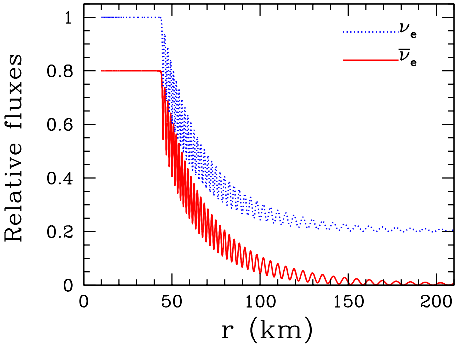
- Both interactions with neutrinos and ordinary matter can play a role



Supernova neutrinos (cont.)



Hannestad, Raffelt, Sigl, Wong, Phys. Rev. D74 (2006) 105010

- Inverted neutrino mass hierarchy (non-zero vacuum mixing)

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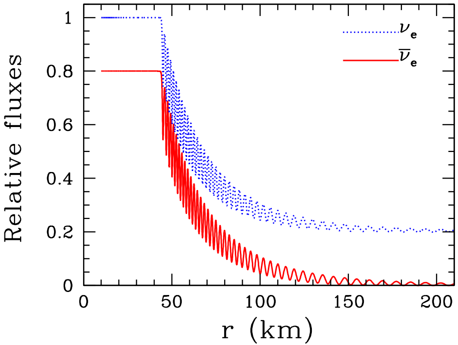

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- No flavor conversion in normal mass hierarchy

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- In the standard case, $\mathbf{D}$ rotates around the vacuum hamiltonian vector, leading to essentially conserved D_z
- The potential energy of the pendulum is essentially $\omega \mathbf{B} \cdot (\mathbf{P} + \bar{\mathbf{P}})$, where ω is the vacuum oscillation frequency

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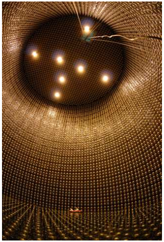

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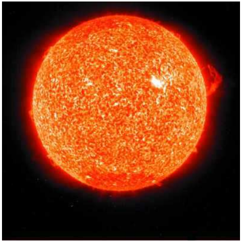

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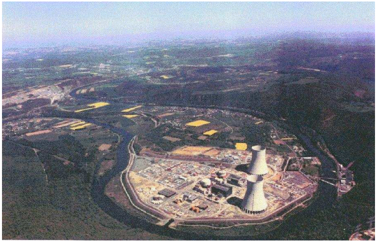

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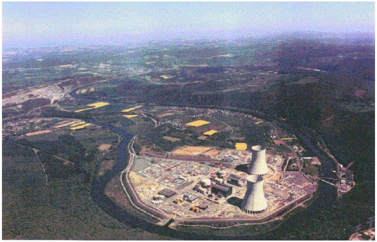

- Examples of scenarios studied:
  - Atmospheric neutrinos
  - Solar neutrinos
  - Long baseline neutrinos
  - Reactor neutrinos
- We wish to study effective nonstandard four-neutrino interactions, e.g.,

$$\nu_e + \nu_e \longrightarrow \nu_e + \nu_\mu$$

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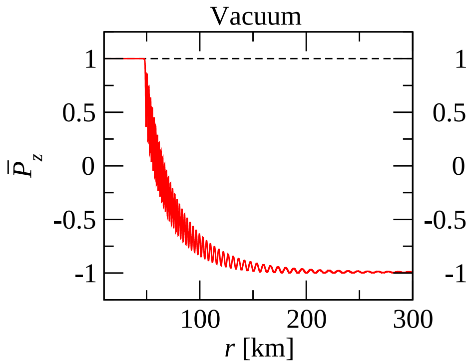
- For typical supernova neutrino energies, $|\omega| \sim 0.3 \text{ km}^{-1}$
- We use $\xi = 0.25$, thus the NSI strength is comparable to the vacuum oscillation strength at the neutrino sphere when $g \simeq 10^{-4}$
- We thus consider $g \lesssim 10^{-4}$ the *small NSI regime*

Small NSI regime (cont.)



- $g = 10^{-7}$ or even smaller is enough to trigger the instability $\longrightarrow$ flavor conversion in the inverted mass hierarchy
- Otherwise, the standard scenario is recovered

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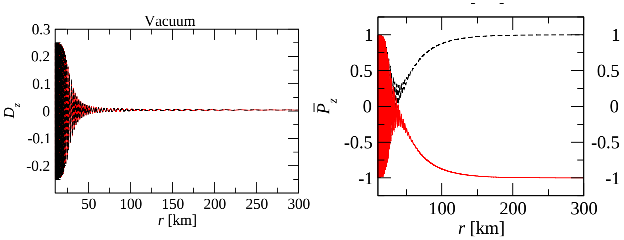
- In this regime, the neutrino NSI initially dominate the vacuum frequency, but the second-order effects are still suppressed
- The NSI act as an external force on the pendulum, making it oscillate rapidly in the beginning of the evolution while not preserving D_z

Intermediate NSI regime (cont.)



- The flavor asymmetry for intermediate $g = 10^{-2}$ erases the initial flavor asymmetry
- The oscillations are damped out when ω starts dominating
- The standard interactions then provide the usual potential, splitting the cases of normal and inverted hierarchy

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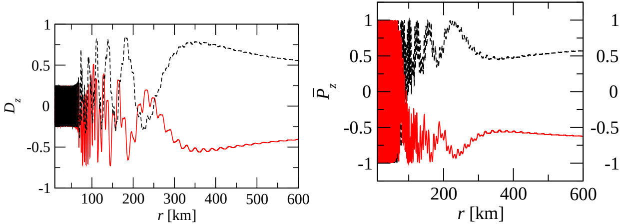
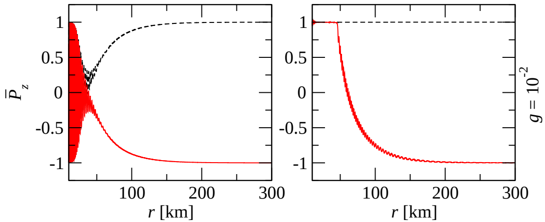
Large NSI regime (cont.)



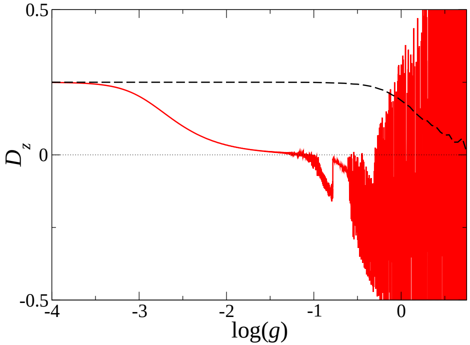
- For large $g = 1$, the final D_z is unpredictable
- The standard potential effect takes over in the end

Stabilization of the intrmediate NSI regime



- For $g = 10^{-2}$, the matter term has stabilized the initial system
- The evolution proceeds more or less as in the standard case
- The NSI is still enough to provide the initial instability, leading to flavor conversions for the inverted mass hierarchy

Overview of results



- For large NSI, the standard matter effect may not be enough to completely stabilize the system
- This again leads to some amount of flavor equilibration

Application to supernovae

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  - Some exceptions may exist, such as O-Ne-Mg progenitors with rapidly decresing density profiles
  - Would require a detailed study

Summary

- We have studied the effect of nonstandard neutrino self-interactions in dense neutrino gases
- We have considered both the case of vacuum or matter backgrounds
- We found that the nonstandard interactions can lead to a flavor equilibration, especially in vacuum

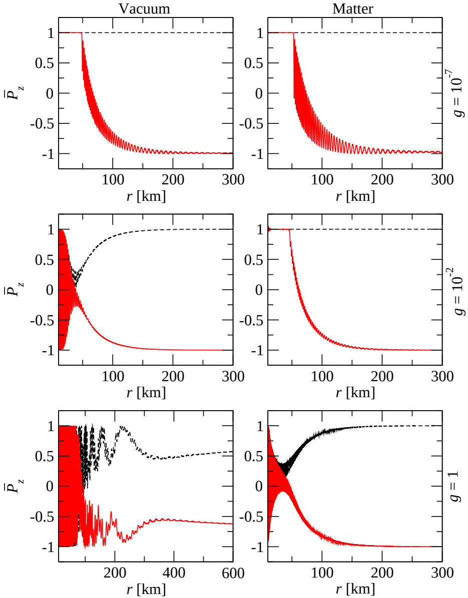
Conclusion and outlook

- For small nonstandard interactions, the standard dynamics can be initiated even if there is no vacuum mixing
- Matter effects will in general be able to stabilize the system
- The standard flavor evolution of supernova neutrinos is relatively stable to NSI
  - Some exceptions may exist

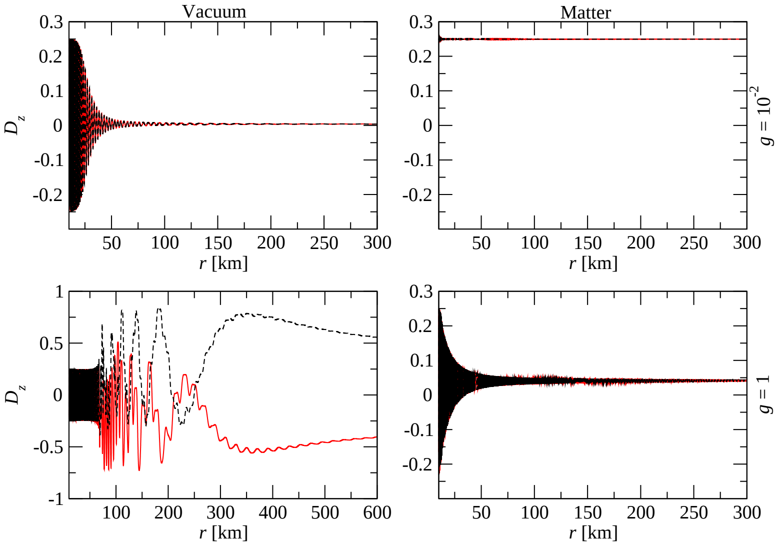
4 Complete figures

5 References

$\bar{P}_z$


Vacuum
Matter
$\bar{P}_z$
r [km]
$g = 10^{-7}$
$g = 10^{-2}$
$g = 1$
1
0.5
0
-0.5
-1
100
200
300
400
600

D_z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-0.1
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250
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1
0.5
-0.5
-1
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4 Complete figures

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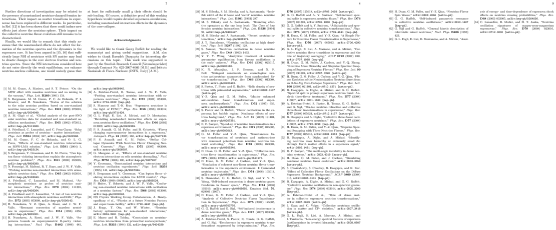

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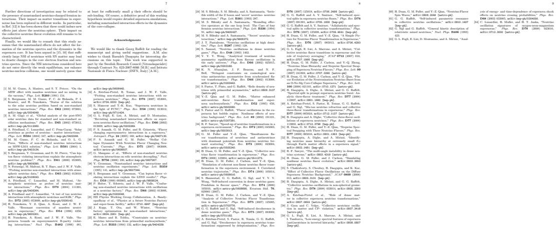

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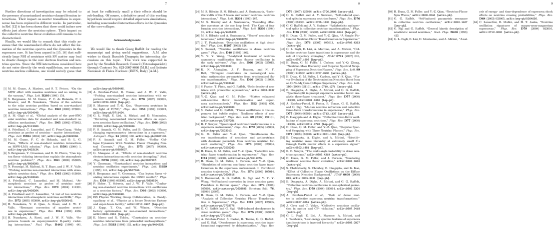

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- See arXiv:0810.2297 for (probably still incomplete) list of refernces